

A SYSTEM FOR CATALYTIC COMBUSTION

FIELD OF INVENTION

This invention relates to catalytic combustion.

5 BACKGROUND OF THE INVENTION

A catalytic combustion gas turbine system has been developed to replace conventional industrial gas turbines, burning natural gas, but with ultra low NOx emissions. One of the features of this turbine is that
10 cooling is required at the inlet of the turbine because of the high inlet temperature ($> 850^{\circ}\text{C}$), arising from combustion of high concentrations of methane. This cooling is achieved by bypassing a substantial amount of the air from the compressor discharge to the turbine inlet
15 and turbine first stage. However, if the air contains methane, this results in a large amount of uncombusted methane passing through the turbine and into the atmosphere. Not only is this an inefficient use of the methane, but it is also damaging to the environment and a
20 waste of energy.

Another application of catalytic combustion turbine systems has been to generate electricity from waste gases, which have a lower concentration of methane than natural gas. However, previous attempts of this have
25 run into several difficulties; having to inject support fuel (eg. natural gas) into the catalytic combustor to maintain efficient combustion, not being able to efficiently handle gas streams with less than 2 mole% methane, having to excessively raise the pressure of the
30 gas stream thereby reducing the overall electrical output of the system, and having difficulty in controlling the gas temperature at the outlet of the combustor at a constant value below 800°C so that cooling at the inlet of the turbine is not required, and having problems in
35 handling the waste gas, which by its nature has a fluctuating composition.

SUMMARY OF THE INVENTION

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Accordingly, it is desirable, if in one embodiment of the present invention, that there is provided a catalytic combustion gas turbine system which utilises a gas with a substantially constant and low concentration of fuel.

According to a first aspect of the present invention there is provided a system for providing fuel to drive a catalytic combustion gas turbine system the system for providing fuel comprising a mixer, having an outlet stream and at least two inlet streams and a compressor, having an inlet stream, the outlet stream of the mixer being connected to the inlet stream of the compressor, wherein, during operation of the system, the at least two inlet streams are controlled so that the outlet stream of the mixer has a substantially constant composition over time.

Preferably, the outlet stream of the mixer has a low concentration of hydrocarbons.

Preferably, the outlet stream of the mixer is substantially a gas.

Preferably, the outlet stream of the mixer has a low concentration of methane.

Preferably, the outlet stream has a concentration of methane of 0.5 to 1.5 mole%.

Preferably, the outlet stream has a concentration of methane of approximately 1 mole%.

Preferably, of the at least two inlet streams of the mixer, at least one inlet stream has a very low concentration of methane and at least one other inlet stream has a high concentration of methane.

Preferably, of the at least two inlet streams of the mixer, at least one inlet stream has a concentration of methane of 0 to 1.5 mole%, and at least one other inlet stream has a concentration of methane of over 20 mole%.

Preferably, the operating temperature of the mixer is approximately 20°C.

Preferably, the operating pressure of the mixer

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is approximately atmospheric.

Preferably, the compressor has a compression ratio of approximately 2.

Preferably, the compressor has an outlet stream
5 which has a pressure of less than 3.5 bar (absolute).

Preferably, the pressure of the outlet stream of the compressor is approximately 2 bar (absolute).

Preferably, the temperature of the outlet stream with the compressor is 100 to 200°C.

10 Preferably, the compressor is an axial flow compressor.

Alternatively, the compressor is a radial flow compressor.

Preferably, at least one of the at least two
15 inlet streams of the mixer is a stream of ventilation air from a coal mine, having very low methane concentration.

Preferably, the system further comprises a first scrubber, the first scrubber having an inlet stream and a gas outlet stream, the gas outlet stream being connected
20 to at least one of the at least two inlet streams of the mixer, and the inlet stream being the stream of ventilation air, wherein, the first scrubber removes particles from the ventilation air through a solid outlet stream.

25 Preferably, the first scrubber comprises a wet scrubber and filter.

Preferably, the first scrubber removes particles greater than and equal to 0.50 micron in diameter.

Preferably, the scrubber also removes sulphur
30 compounds through a sulphur outlet stream.

Preferably, the first scrubber removes sulphur compounds, so that the concentration of hydrogen sulphide and sulphur dioxide in the gas outlet stream is no greater than 10ppm and 5ppm respectively.

35 Preferably, at least one other stream of the at least two inlet streams of the mixer is a stream of coal mine drainage gas.

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Preferably, the system further comprises a second scrubber, the second scrubber having an inlet stream and a gas outlet stream, the gas outlet stream being connected to at least one other of the at least two inlet streams of the mixer, and the inlet stream being the stream of coal mine drainage gas, wherein, the second scrubber removes particles from the drainage gas through a solid outlet stream.

Preferably, the second scrubber comprises a wet scrubber and filter.

Preferably, the second scrubber removes particles greater than and equal to 0.50 micron in diameter.

Preferably, the scrubber also removes sulphur compounds through a sulphur outlet stream.

Preferably, the second scrubber removes sulphur compounds, so that the concentration of hydrogen sulphide and sulphur dioxide in the gas outlet stream is no greater than 10ppm and 5ppm respectively.

Preferably, the system further comprises a reservoir, the reservoir having an outlet stream connected to the inlet stream of the compressor, and during operation of the system, the outlet stream of the reservoir has a substantially constant composition over time, wherein, the reservoir stores enough fluid to buffer fluctuations in the composition of at least one inlet stream of the reservoir.

Preferably, the reservoir stores a gas.

Preferably, the outlet stream of the mixer is connected to the at least one inlet stream of the reservoir, wherein the mixer and the reservoir are separate units.

Alternatively, the mixer is large enough to act as the reservoir.

Preferably, the operating temperature of the reservoir is approximately 20°C.

Preferably, the operating pressure of the reservoir is approximately atmospheric.

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According to a second aspect of the present invention there is provided a system comprising:

a compressor having an inlet stream and an outlet stream, a pre-heater having a process inlet stream and a process outlet stream, a catalytic combustor having an inlet stream and an outlet stream and containing a catalyst, and a turbine having an inlet stream and an outlet stream, wherein, the outlet stream of the compressor is connected to the process inlet stream of the pre-heater, the process outlet stream of the pre-heater is connected to the inlet stream of the catalytic combustor, and the outlet stream of the catalytic combustor is connected to the inlet stream of the turbine, and wherein, during operation of the system, the inlet stream of the compressor has a substantially constant and low concentration of fuel.

Preferably, the inlet stream of the compressor has a low concentration of hydrocarbons.

Preferably, the inlet stream with the compressor is substantially a gas.

Preferably, the inlet stream of the compressor has a low concentration of methane.

Preferably, the inlet stream of the compressor has a methane concentration of 0.5 to 1.5 mole%.

Preferably, the inlet stream of the compressor has a methane concentration of approximately 1 mole%.

Preferably, the inlet stream of the compressor has a temperature of approximately 20°C.

Preferably, the inlet stream of the compressor has a pressure of approximately atmospheric.

Preferably, the system further comprises a mixer, having an outlet stream connected to the inlet stream of compressor, wherein, during operation of the system at least two inlet streams to the mixer are controlled so that the outlet stream has the substantially constant and low concentration of fuel.

Preferably, of the at least two inlet streams of

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the mixer, at least one inlet stream has a very low concentration of methane and at least one other inlet stream has a high concentration of methane.

5 Preferably, of the at least two inlet streams of the mixer, at least one inlet stream has a concentration of methane of 0 to 1.5 mole% and at least one other inlet stream has a concentration of methane of over 20 mole%.

Preferably, the compressor has a compression ratio of approximately 2.

10 Preferably, the outlet stream of the compressor has a pressure of less than 3.5 bar (absolute).

Preferably, the pressure of the outlet stream of the compressor is approximately 2 bar (absolute).

15 Preferably, the temperature of the outlet stream of the compressor is 100 to 200°C.

Preferably, the compressor is an axial flow compressor.

Alternatively, the compressor is a radial flow compressor.

20 Preferably, at least one of the at least two inlet streams of the mixer is a stream of ventilation air from a coal mine.

Preferably, the system further comprises a first scrubber, the first scrubber having an inlet stream and a gas outlet stream, the gas outlet stream being connected to at least one of the at least two inlet streams of the mixer, and the inlet stream being the stream of ventilation air, wherein, the first scrubber removes particles greater than and equal to 0.50 micron in diameter from the ventilation air through a solid outlet stream, and the first scrubber also removes sulphur compounds from the ventilation air through a sulphur outlet stream, so that the concentration of hydrogen sulphide and sulphur dioxide in the gas outlet stream is no greater than 10ppm and 5ppm respectively.

Alternatively, the first scrubber could be connected between the mixer and the compressor.

Preferably, at least one other stream of the at least two inlet streams of the mixer is a stream of coal mine drainage gas.

5 Preferably, the system further comprises a second scrubber, the second scrubber having an inlet stream and a gas outlet stream, the gas outlet stream being connected to at least one of the at least two inlet streams of the mixer, and the inlet stream being the stream of coal mine drainage gas, wherein the second scrubber removes
10 particles greater than and equal to 0.50 micron from the ventilation air through a solid outlet stream and also removes sulphur compounds from the ventilation air through a sulphur outlet stream so that the concentration of hydrogen sulphide and sulphur dioxide in the gas outlet
15 stream is no greater than 10ppm and 5 ppm respectively.

Preferably, the system further comprises a reservoir, the reservoir having an outlet stream connected to the inlet stream of the compressor, and during operation of the system, the outlet stream of the
20 reservoir has a substantially constant composition over time, wherein, the reservoir stores enough fluid to buffer fluctuations in the composition of at least one inlet stream to the reservoir.

Preferably, the reservoir stores the gas.
25 Preferably, the outlet stream of the mixer is connected to the at least one inlet stream of the reservoir, wherein the mixer and the reservoir are separate units.

Alternatively, the mixer is large enough to act
30 as a reservoir.

Preferably, the operating temperature of the reservoir is approximately 20°C.

Preferably, the operating pressure of the reservoir is approximately atmospheric.

35 Preferably, the process outlet stream of the pre-heater has a temperature of 475 to 535°C.

Preferably, there is a very low pressure drop

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across the pre-heater, such that the pressure of the process outlet stream is substantially the same as the pressure of the process inlet stream.

Preferably, the catalytic combustor has a moderate space velocity and a low pressure drop.

Preferably, the catalytic combustor contains a catalyst having a high activity and a high reaction surface area.

Preferably, the activity of the catalyst is $50\sim 200 \times 10^{-7}$ mole/(m²s).

Preferably, the reaction surface area of the catalyst is 20~40m²/cm³.

Throughout the specification, the term "activity" is understood to refer to the methane oxidation rate.

Preferably, the catalytic combustor is a honeycomb-type monolith reactor.

Preferably, the catalyst used in the catalytic combustor is a noble metal catalyst.

Preferably, the catalyst used in the catalytic combustor is at least one of either palladium, platinum or rhodium.

Preferably, the monolith is a ceramic, which acts as a substrate for a wash coat slurry of base metals on which the noble metal catalyst is placed.

Preferably, the catalytic combustor has a maximum continuous bed service temperature of 950°C.

Preferably, the outlet stream for the catalytic combustor has a temperature of no more than 800°C.

Preferably, the catalytic combustor has a combustion efficiency of greater than 99%.

Preferably, there is a very low pressure drop across the catalytic combustor, such that the pressure of the outlet stream is substantially the same as the pressure of the inlet stream.

Preferably, the inlet stream of the turbine has a temperature of less than 800°C.

Preferably, the inlet stream of the turbine has a

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temperature of approximately 780°C.

Preferably, the outlet stream of the turbine has a temperature of approximately 630°C.

5 Preferably, the outlet stream of the turbine has a pressure slightly above atmospheric.

Preferably, the turbine does not require cooling air from the outlet stream of the compressor to cool the inlet scroll and the first stage of the turbine.

10 Preferably, the turbine has cooling oil for cooling the shaft and the bearings.

Preferably, the turbine is an axial flow turbine.

Alternatively, the turbine is a radial flow turbine.

15 Preferably, the turbine is used to drive the compressor.

Preferably, the system further comprises a generator, which is connected to the turbine, wherein the generator converts the shaft work produced by the turbine into electrical energy.

20 Alternatively, the turbine comprises two turbines based on a split-shaft cycle such that the first turbine drives the compressor, and the second turbine is connected to the generator.

25 Preferably, the system further comprises a recuperator to recover some of the energy in the outlet stream of the turbine.

30 Preferably, the recuperator and the pre-heater form a single integral unit, wherein, the pre-heater has a heating inlet stream and a heating outlet stream, the heating inlet stream being connected to the outlet stream of the turbine, such that the outlet stream of the turbine is used to heat the outlet stream of the compressor.

Preferably, the pre-heater is a plate heat exchanger.

35 Alternatively, the pre-heater is a fin-tube heat exchanger.

Alternatively the pre-heater and the recuperator

are separate units such that the outlet stream of the compressor is heated in the pre-heater by heating means other than using the outlet stream of the turbine.

5 Preferably, the system further comprises a heat recovery boiler, the boiler having an inlet stream connected to the heating outlet stream of the pre-heater, wherein the boiler is adapted, in use, to recover energy from the turbine outlet stream.

10 Preferably, the system further comprises a pre-burner, having an inlet stream, an outlet stream and a start-up fuel stream, the inlet stream being connected to the process outlet stream of the pre-heater, and the outlet stream being connected to the inlet stream of the catalytic combustor, wherein the pre-burner is used to
15 combust the start-up fuel stream during start-up of the turbine and during low load operation.

Preferably, the start-up fuel is a hydrocarbon.

Preferably, the start-up fuel is liquid petroleum gas.

20 Preferably, during normal operation of the system, the start-up fuel stream has a flow rate of 0, and the process outlet stream of the pre-heater passes through the pre-burner unreacted.

25 According to a third aspect of the present invention there is provided a method of producing a gas with a substantially constant and low concentration of fuel, the method comprising the steps of specifying a desired concentration of fuel in the outlet stream of a mixer, mixing at least one stream with a very low
30 concentration of fuel with at least one stream with a high concentration of fuel in the mixer and controlling the flow rate of the at least one stream with a high concentration of fuel to meet the desired concentration of fuel in the outlet stream of the mixer.

35 Preferably, the fuel is a hydrocarbon fuel.

Preferably, the fuel is methane.

Preferably, the desired concentration of methane

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is 0.5 to 1.5 mole%.

Preferably, the desired concentration of methane is approximately 1 mole%.

Preferably, the at least one stream with a very
5 low concentration of fuel, has a concentration methane of 0 to 1.5 mole%.

Preferably, the at least one stream with a high concentration of fuel has a concentration methane of over 20 mole%.

10 Preferably, the at least one stream with a very low concentration of fuel is a stream of ventilation air from a coal mine.

Preferably, the at least one stream with a high concentration of fuel is a stream of coal mine drainage
15 gas.

Preferably, the method further comprises the step of scrubbing the ventilation air to remove particles using a first scrubber.

20 Preferably, the method further comprises the step of scrubbing the ventilation air to remove particles greater than and equal to 0.50 micron in diameter using the first scrubber.

Preferably, the method further comprises the step of scrubbing the ventilation air to remove sulphur
25 compounds using the first scrubber.

Preferably, the method further comprises the step of scrubbing the ventilation air to remove sulphur compounds using the first scrubber so that the first
30 scrubber has a gas outlet stream which has a concentration of hydrogen sulphide and sulphur dioxide of no greater than 10ppm and 5ppm respectively.

Preferably, the method further comprises the step of scrubbing the coal mine drainage gas to remove particles using a second scrubber.

35 Preferably, the method further comprises the step of scrubbing the coal mine drainage gas to remove particles greater than and equal to 0.50 micron in

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diameter, using the first scrubber.

Preferably, the method further comprises the step of scrubbing the coal mine drainage gas to remove sulphur compounds using the second scrubber.

5 Preferably, the method further comprises the step of scrubbing the coal mine drainage gas to remove sulphur compounds using the second scrubber so that the second scrubber has a gas outlet stream which has a concentration of hydrogen sulphide and sulphur dioxide of no greater
10 than 10ppm and 5ppm respectively.

Preferably, the method further comprises the step of storing the gas in a reservoir.

Preferably, the mixer is large enough to act as the reservoir.

15 Alternatively, the outlet stream of the mixer is connected to an inlet stream of the reservoir, wherein the mixer and the reservoir are separate units.

According to a fourth aspect of the present invention there is provided a method of producing
20 electricity, the method comprising the steps of, mixing at least two gas streams to produce a process gas stream with a substantially constant and low fuel concentration prior to, compressing the process gas stream, preheating the process gas stream, combusting the process gas stream in
25 the presence of a catalyst, expanding the process gas stream in a turbine to produce shaft work, converting the turbine shaft work to electricity using a generator.

Preferably, the step of mixing at least two gas streams, comprises the method of producing a gas with a
30 low concentration of fuel in accordance with the third aspect of the present invention.

Preferably, the process gas stream is compressed to 1.5 to 3.5 bar (absolute).

Preferably, the process gas stream is compressed
35 to approximately 2 bar (absolute).

Preferably, the process gas stream is preheated to 475 to 535°C.

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Preferably, the catalyst is a noble metal catalyst.

Preferably, the catalyst is at least one of either palladium, platinum or rhodium.

5 Preferably, the catalyst is placed on a ceramic monolith, which acts as a substrate for wash coat slurry of base metals.

Preferably, a stream includes a fluid in a conduit.

10 The words "comprising, having including" should be interpreted in an inclusive sense, meaning that additional features may also be added.

Variations and modifications can be made in respect of the invention described above and defined in
15 the following statement of claim.

BRIEF DESCRIPTION OF THE DRAWINGS

Preferred embodiments of the invention will now be described, by way of example only, with reference to the accompanying drawings in which:

20 Figure 1 is a block diagram of a catalytic combustion gas turbine system.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

With reference to Figure 1, a preferred embodiment of a catalytic combustion gas turbine system
25 comprises a compressor 10, a recuperator 11, a pre-burner 12, a catalytic combustor 13, a turbine 14, a generator 15, a mixer 16, and first and second scrubbers 17, 18 thereby forming a power generation system which can be powered with approximately 1 mole% methane (maximum 1.5
30 mole%, minimum 0.5 mole%).

The system is predominantly powered by the methane in the ventilation air from a coal mine 21. The ventilation air is scrubbed in the first scrubber 17, to remove dust particles greater than and equal to 0.50
35 micron in diameter. The first scrubber 17 also removes hydrogen sulphide and sulphur dioxide so that the concentration of these compounds does not exceed the

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maximum allowable concentration in the system, which is 10ppm for hydrogen sulphide and 5ppm for sulphur dioxide. Exceedance of the maximum allowable concentrations can lead to fouling of the system components and deactivation of the catalyst in the catalytic combustor.

Having been scrubbed in the first scrubber 17, the ventilation air then enters the mixer 16 through a first inlet 22. Because the concentration of methane in the ventilation air 21 can vary between 0 and 1.5 mole%, it is necessary to mix it with another gas so as to provide a gas with nearly constant methane concentration over time to the compressor 10. This is achieved using coal mine drainage gas 20, which is also subjected to a similar scrubbing operation in the second scrubber 18. The second scrubber 18, removes dust particles and hydrogen sulphide and sulphur dioxide to the same levels as the first scrubber 17, before the drainage gas 20 enters the mixer 16 through a second inlet 23. The drainage gas has a methane concentration of over 20 mole%.

The mixer 16 operates at approximately 20°C and atmospheric pressure. The amount of drainage gas 20 that is mixed with the ventilation air 21 is controlled so that at the mixer's outlet 24, the concentration of methane in the gas is generally constant over time.

The system further comprises a reservoir (not shown) which is connected to the outlet of the mixer 24. The reservoir stores a large amount of the mixed gas at approximately 20°C and atmospheric pressure. The purpose of the reservoir is to buffer the downstream components of the system from possible fluctuations in the concentration of methane in the gas from the outlet 24 of the mixer 16.

The gas flows from the outlet of the reservoir to the inlet 25 of the compressor 10. The compressor 10 has a compressor ratio of approximately 2. This means that the pressure of the gas at the outlet 26 of the compressor 10, will be approximately 2 bar. For efficient operation of the system, the pressure at the outlet 26 of the

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compressor 10 should be no greater than 3.5 bar. The compressor 10 can be either an axial flow compressor or a radial flow compressor. The temperature of the gas at the outlet 26 of the compressor 10 will be 100 to 200°C.

5 From the outlet 26 of the compressor 10, the gas flows to the primary inlet 27 of the recuperator 11. The recuperator heats the gas so that at the primary outlet 28 of the recuperator 11, the temperature of the gas is between 475 and 535°C. The recuperator 11 operates with a
10 very low pressure drop across the primary inlet 27 and the primary outlet 28, so that the pressure of the primary outlet 28 is very similar to the pressure of the primary inlet 27. Whilst any heating means can be used to heat the gas in the recuperator 11, for efficient energy usage,
15 the present invention utilises the gas exiting the turbine 14 through outlet 35. This gas enters the recuperator 11 through a secondary inlet 36, where it transfers energy to the gas entering through the primary inlet 27, before
20 exiting the recuperator 11 through the secondary outlet 37. This transfer of energy is achieved without any direct physical contact between the two gases, using either a plate heat exchanger or a fin-tube heat exchanger.

The gas exiting the recuperator 11 through
25 primary outlet 28, then flows into the pre-burner 12 through an inlet 29. During normal continuous operation of the system, the gas flows through the pre-burner 12 without any change in its composition, temperature, pressure or other properties, such that the gas exits the
30 pre-burner 12 through outlet 31 unchanged from the gas that entered through inlet 29. The pre-burner 12 is only operated during the start-up of the system and during low load operation. During these instances, start-up fuel such as LPG is injected into the pre-burner through the
35 start-up fuel inlet 30. The pre-burner 12 is then operated to facilitate partial combustion of both the start-up fuel and the gas entering through inlet 29,

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before complete combustion occurs in the catalytic combustor 13.

The gas exiting the pre-burner 12 through outlet 31 flows into the catalytic combustor 13 through an inlet 32. The catalytic combustor 13 is a honeycomb-type monolith reactor. Monoliths have a large open frontal area resulting in a low pressure drop, which is necessary for the required moderate space velocities of the system. Nobel metal catalysts are used in the catalytic combustor 13. The ceramic monolith acts as a substrate for a wash coat slurry of base metals, such as alumina and ceria, on which the nobel metal catalyst such as palladium, platinum or rhodium are placed. The maximum continuous bed service temperature can be 950°C, but for short periods can reach up to 1050°C. The catalytic combustor 13 has a combustion efficiency of over 99%. The gas exiting the combustor 13 through outlet 33 has a temperature of equal to or less than 800°C and a pressure which is similar to that of the gas entering the catalytic combustor through inlet 32. The similar pressure of the gas at the outlet 33 to the inlet 32 is a result of the low pressure drop across the catalytic combustor 13.

The gas from the outlet 33 of the catalytic combustor 13 enters the turbine 14 through an inlet 34. The temperature of the gas at the inlet 34 should be no greater than 800°C, and is generally controlled to be approximately 780°C. If the temperature of the gas becomes elevated above 800°C, then cooling of the inlet scroll and the first stage of the turbine using gas from outlet 26 of the compressor 10 would be required. However, it is a feature of the preferred embodiments of the present invention that such cooling is not required. Cooling oil is supplied to cool the shaft and bearings.

The gas is expanded in the turbine 14 to produce shaft work, resulting in the gas exiting the turbine 14 through outlet 35 having a temperature of approximately 630°C and a pressure of slightly above atmospheric. Some

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of the shaft work of the turbine 14 is used to drive the compressor 10 through the connection 39. The remaining shaft work is converted into electrical energy by the generator 15 which is connected by 38 to the turbine 14.

5 Alternatively, the turbine 14 may comprise two turbines which operate on a split shaft cycle. The first turbine is used to drive the compressor 10 and the second turbine is connected to the generator 15. The turbine(s) 14 can be either an axial flow turbine(s) or a radial flow
10 turbine(s).

The system also includes a waste heat boiler (not shown). The gas exiting the secondary outlet 37 of the recuperator 11 enters the waste heat boiler, where it is processed to recover as much of the remaining energy in
15 the gas as possible.